Jet Propulsion Laboratory
California Institute of Technology

From Cocktail Napkin to Concept Feasibility

Spacecraft Design in Early Formulation with TATER

Presented by Kristina Hogstrom

Co-authors:

Jonathan Murphy, Steven Zusack, Andrew Coffey, Chester Borden,
Alan Didion, Damon Landau, Adam Nelessen, Macon Vining, & Robert Miller

Jet Propulsion Laboratory, Pasadena, CA

JPL Innovation Foundry

Concept Feasibility and the A-Team

From cocktail napkin

To ideas on post-its

Multi -vote

To "crowd favorites"

Cost

Technical Feasibility

Science Value

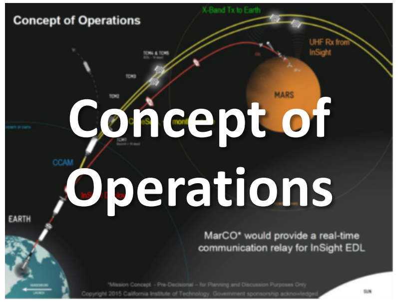
Risk

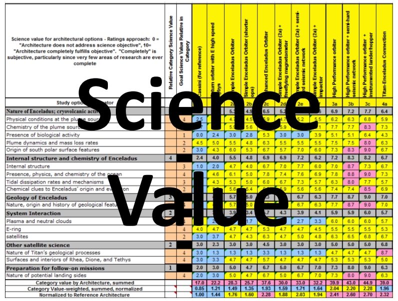
To concepts on quad charts

Need to quantify figures of merit early in the formulation process to select most promising concepts

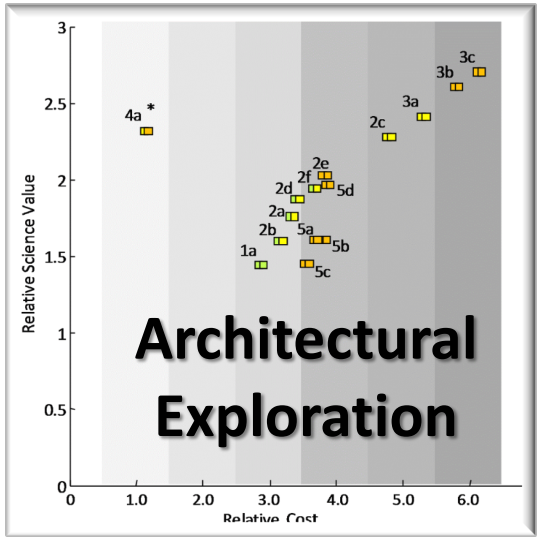
The Toolbox for Architectual Tradespace Exploration and Refinement

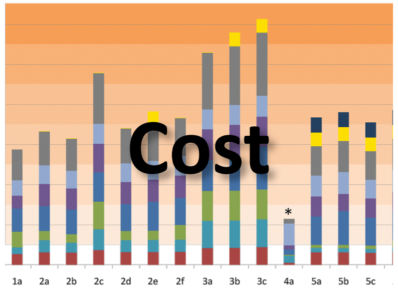
TATER covers all of the driving factors needed to describe and compare concepts

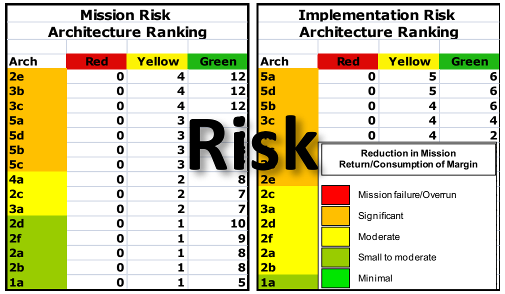




Mission Design







Mission Risk Architecture Ranking

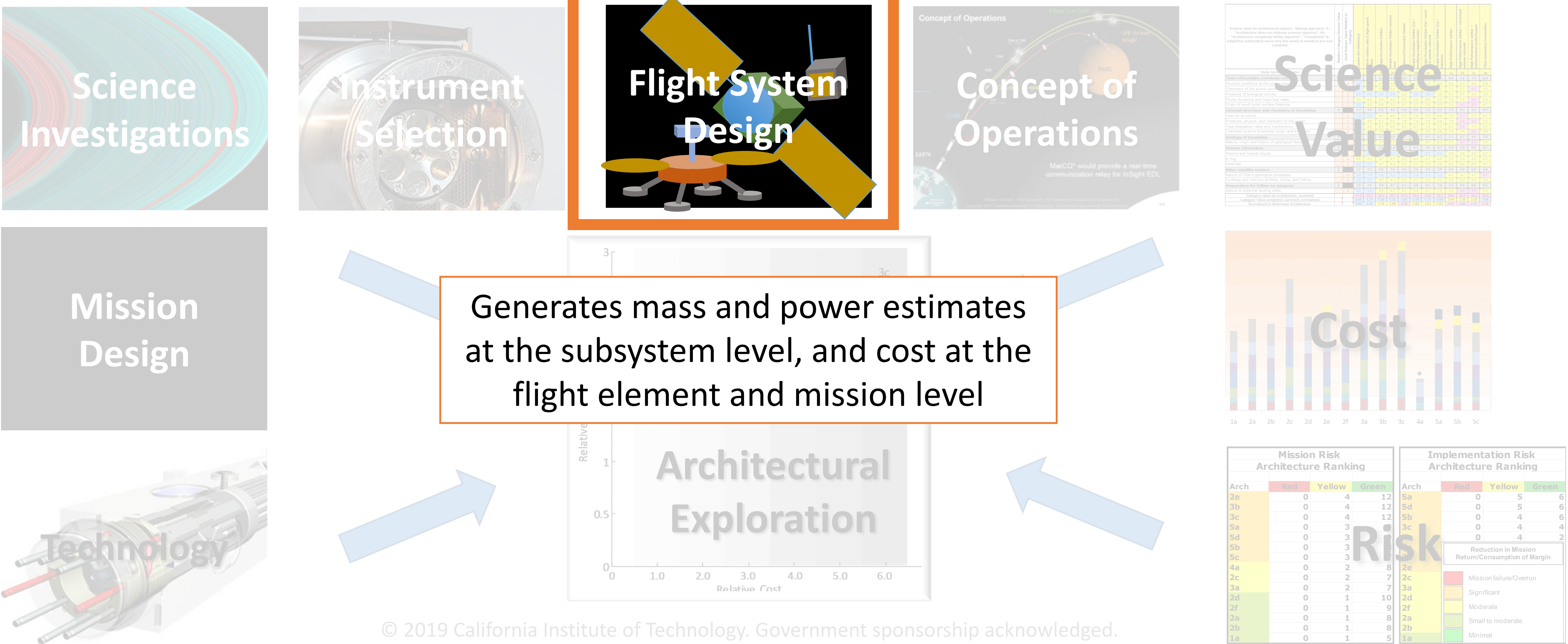
Arch	Red	Yellow	Green
2e	0	4	12
3b	0	4	12
3c	0	4	12
5a	0	3	[illegible]
5d	0	3	[illegible]
5b	0	3	[illegible]
5c	0	3	[illegible]
4a	0	2	8
2c	0	2	7
3a	0	2	7
2d	0	1	10
2f	0	1	9
2a	0	1	8
2b	0	1	8
1a	0	1	5

Implementation Risk Architecture Ranking

Arch	Red	Yellow	Green
5a	0	5	6
5d	0	5	6
5b	0	4	6
3c	0	4	4
[illegible]	0	4	2
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
2e	[illegible]	[illegible]	[illegible]
2c	[illegible]	[illegible]	[illegible]
3a	[illegible]	[illegible]	[illegible]
2d	[illegible]	[illegible]	[illegible]
2f	[illegible]	[illegible]	[illegible]
2a	[illegible]	[illegible]	[illegible]
2b	[illegible]	[illegible]	[illegible]
1a	[illegible]	[illegible]	[illegible]

The Toolbox for Architectural Tradespace Exploration and Refinement

TATER covers all of the driving factors needed to describe and compare concepts

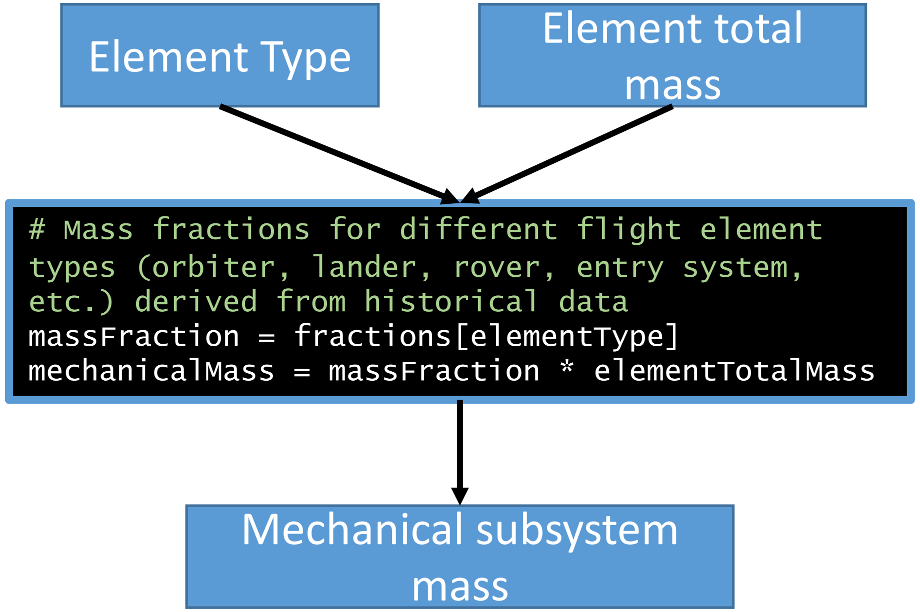


Generates mass and power estimates at the subsystem level, and cost at the flight element and mission level

The TATER Spacecraft Design Model

TATER is a collection of subsystem-level and component-level models, based on physics or regressed from historical data

Model that estimates the mechanical subsystem mass as a fraction of the total flight element mass



The TATER Spacecraft Design Model

TATER is a collection of subsystem-level and component-level models, based on physics or regressed from historical data

Model that estimates the antenna mass as a function of its diameter

Antenna diameter

↓

```
# Mass function regressed from data in Space
Mission Analysis and Design, 3rd edition
Mass = 2.4583 * Diameter + 3.9886 * Diameter**2
```

↓

Antenna mass

The TATER Spacecraft Design Model

TATER is a collection of subsystem-level and component-level models, based on physics or regressed from historical data

Model that computes the total propellant for a given propulsion system based on a table of delta-V maneuvers and other mass-changing events

Maneuvers | Specific impulse | Element dry mass

```
initial_masses = []
final_masses = []
final_mass.append(element_dry_mass)
# Work backwards through an array of delta-V maneuvers
for i in range(0,len(maneuvers)):
   initial_mass = final_mass[i]*math.exp(maneuvers[i]/isp/g0)
   initial_masses.append(initial_mass)
   # The initial mass of this maneuver is the final mass of
the previous maneuver
   final_mass.append(initial_mass)
```

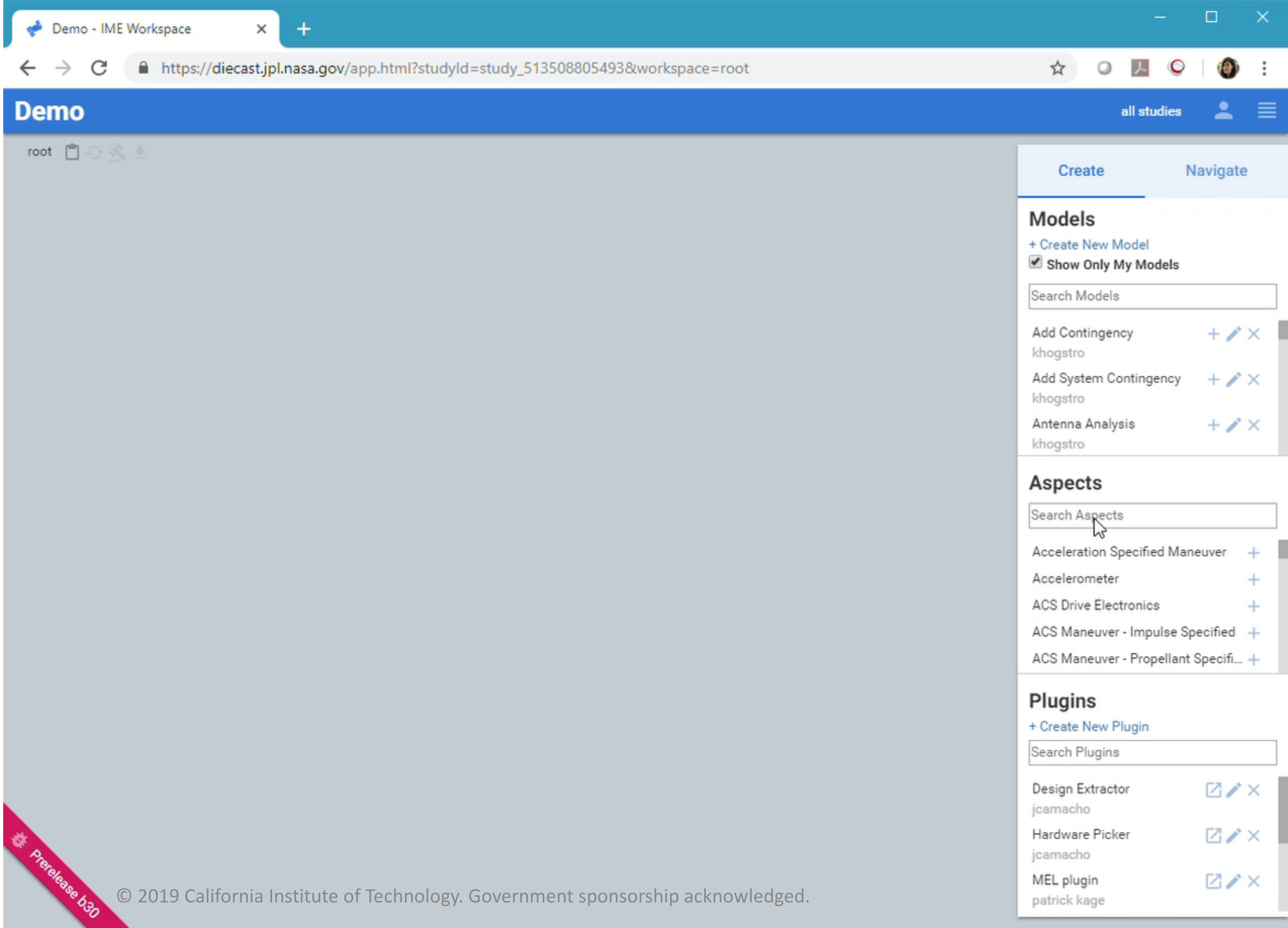
Propellant mass

FOUNDRY FURNACE

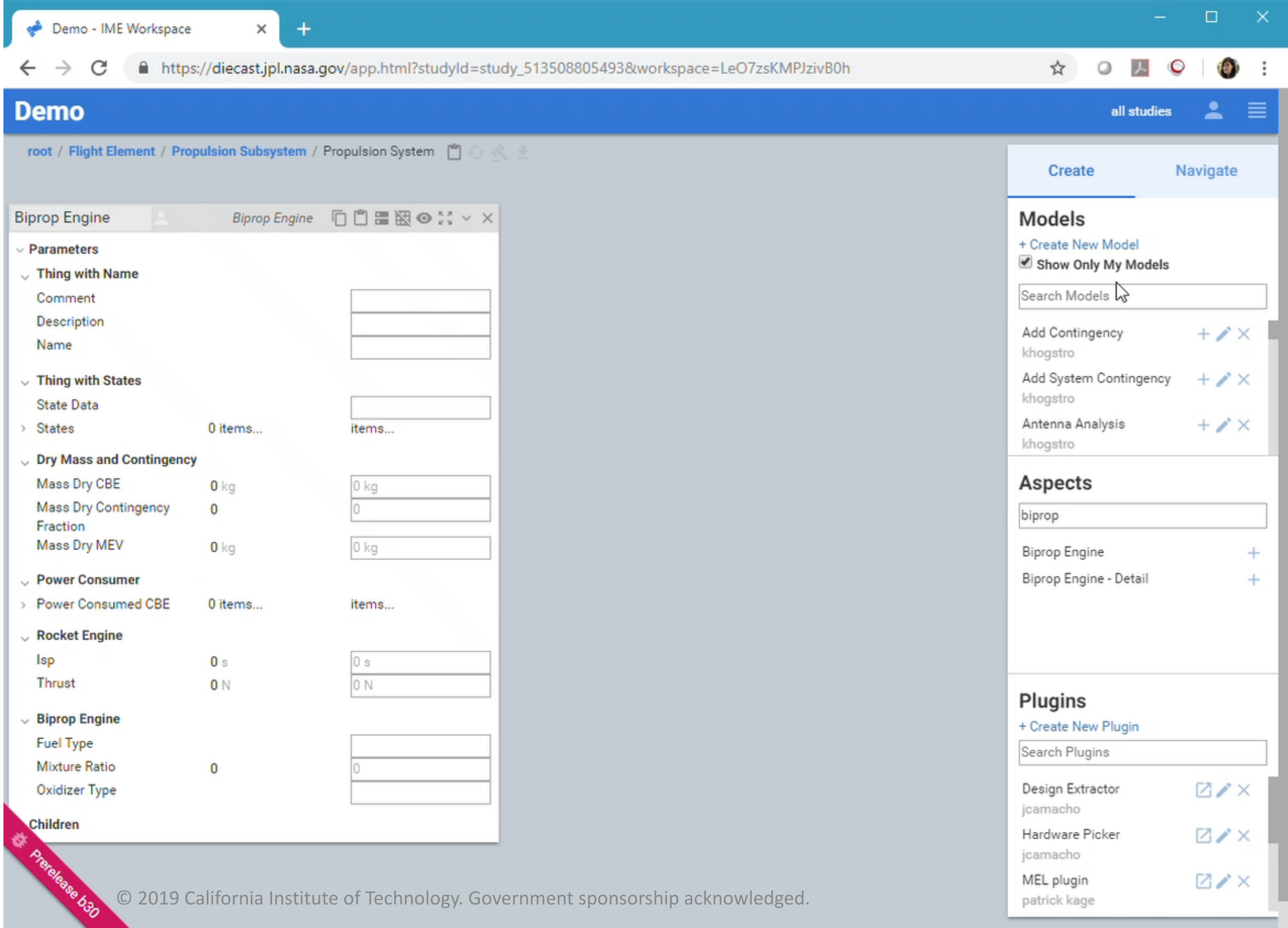
TATER in the Integrated Modeling Environment

Add data blocks with recognizable tags called aspects

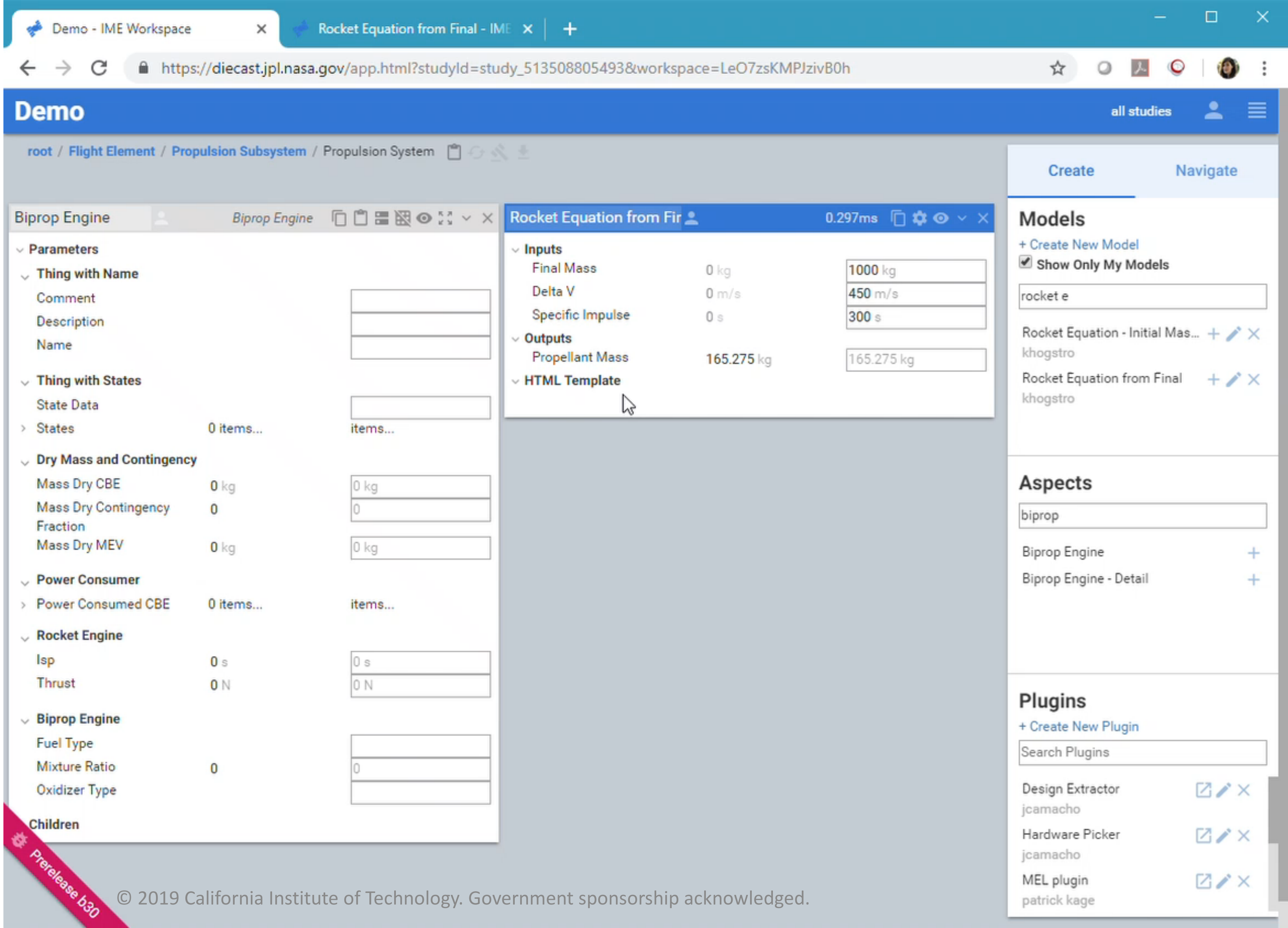
Nest data blocks to create tree structure



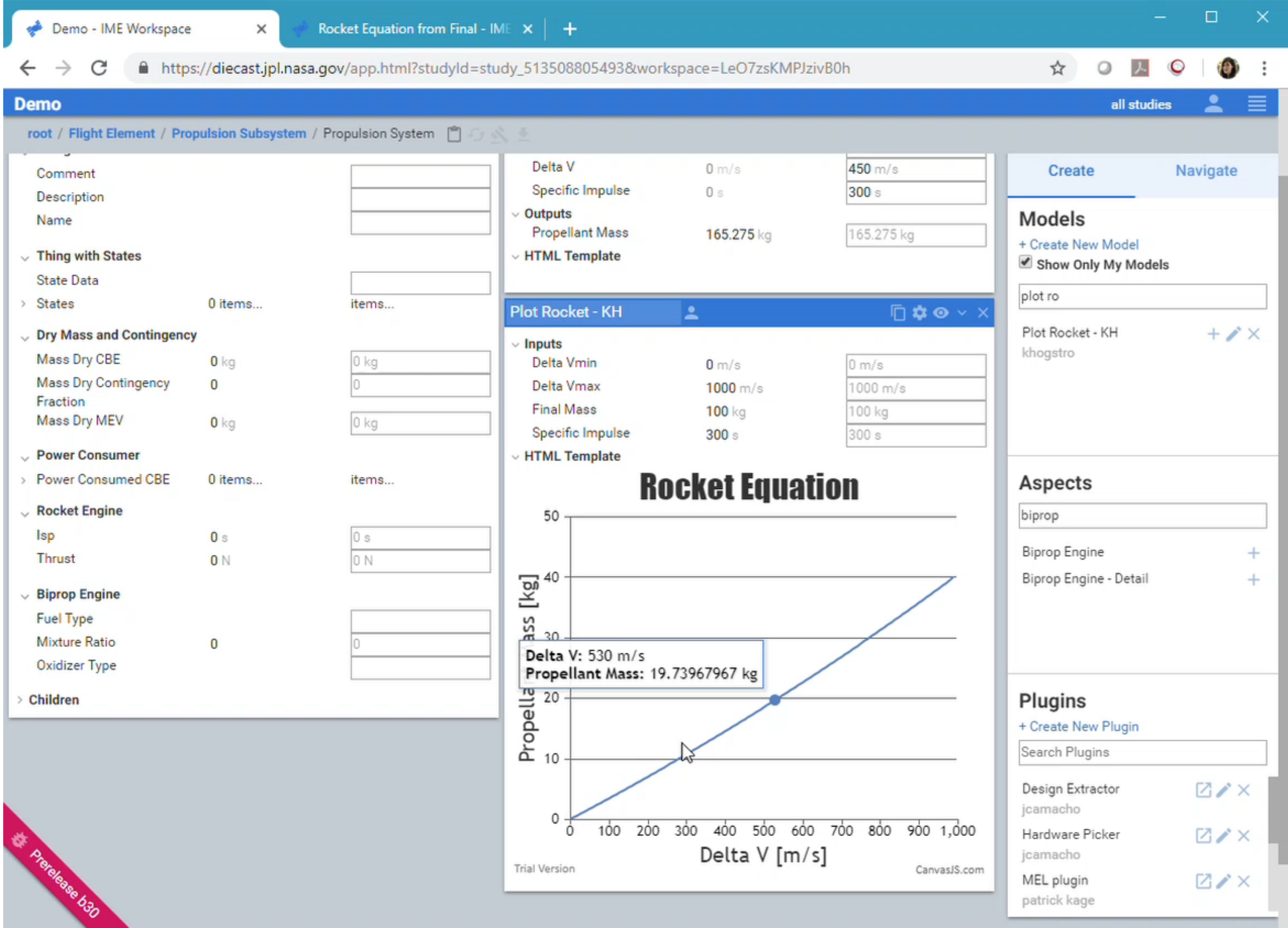
Create models with Python or SpreadJS and visualize with HTML



Create models with Python or SpreadJS and visualize with HTML

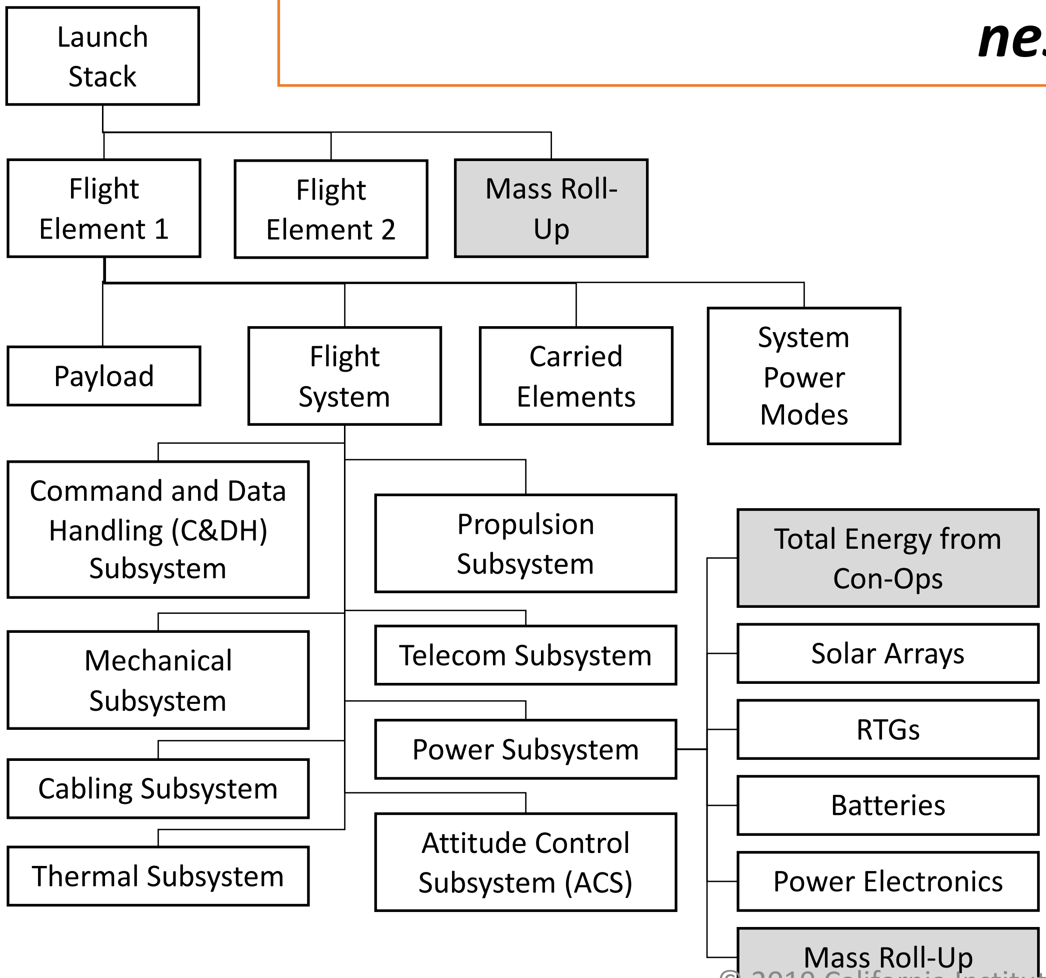


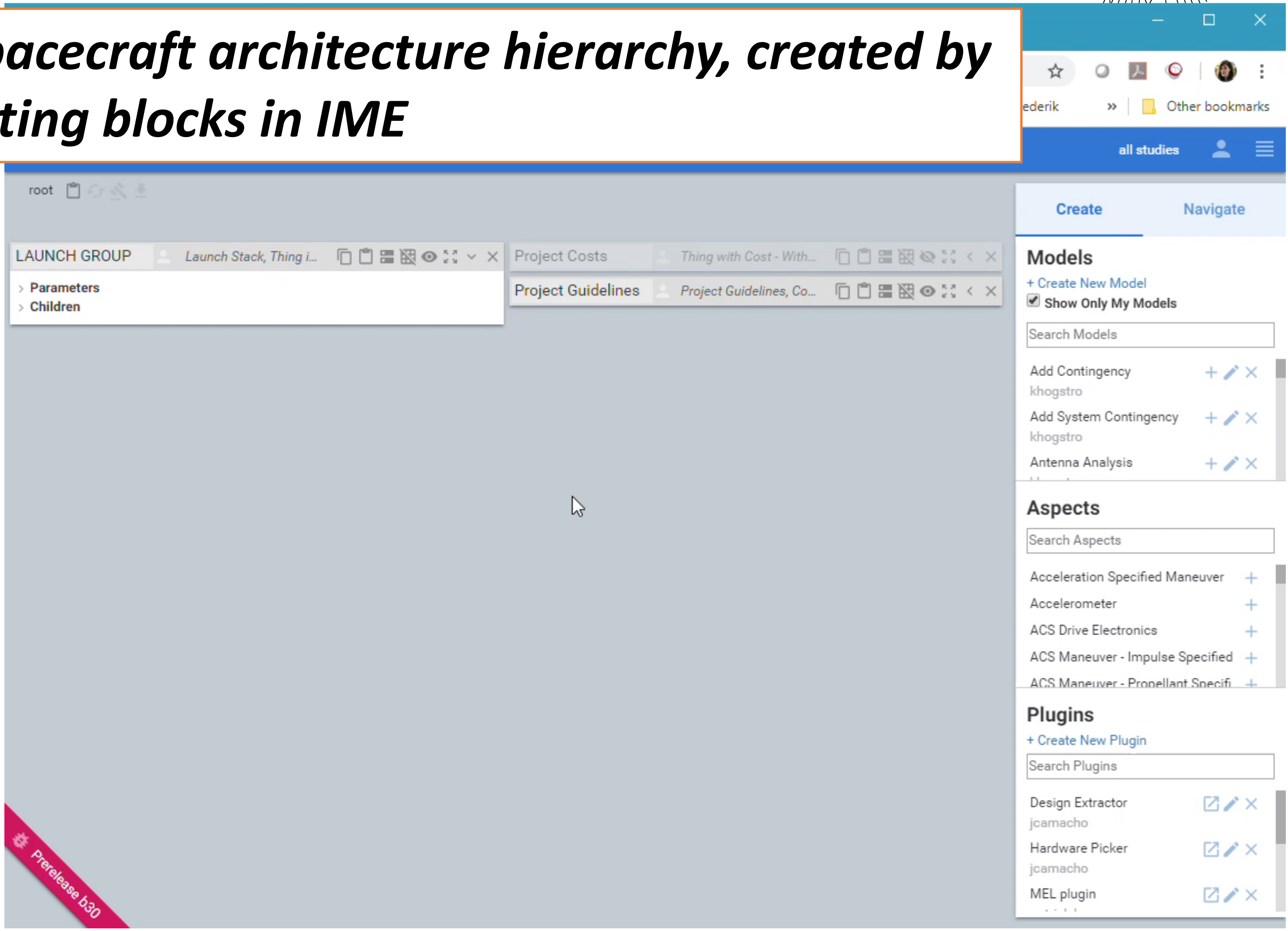
Link blocks together with intuitive path language and dynamic search results



TATER Tree Structure

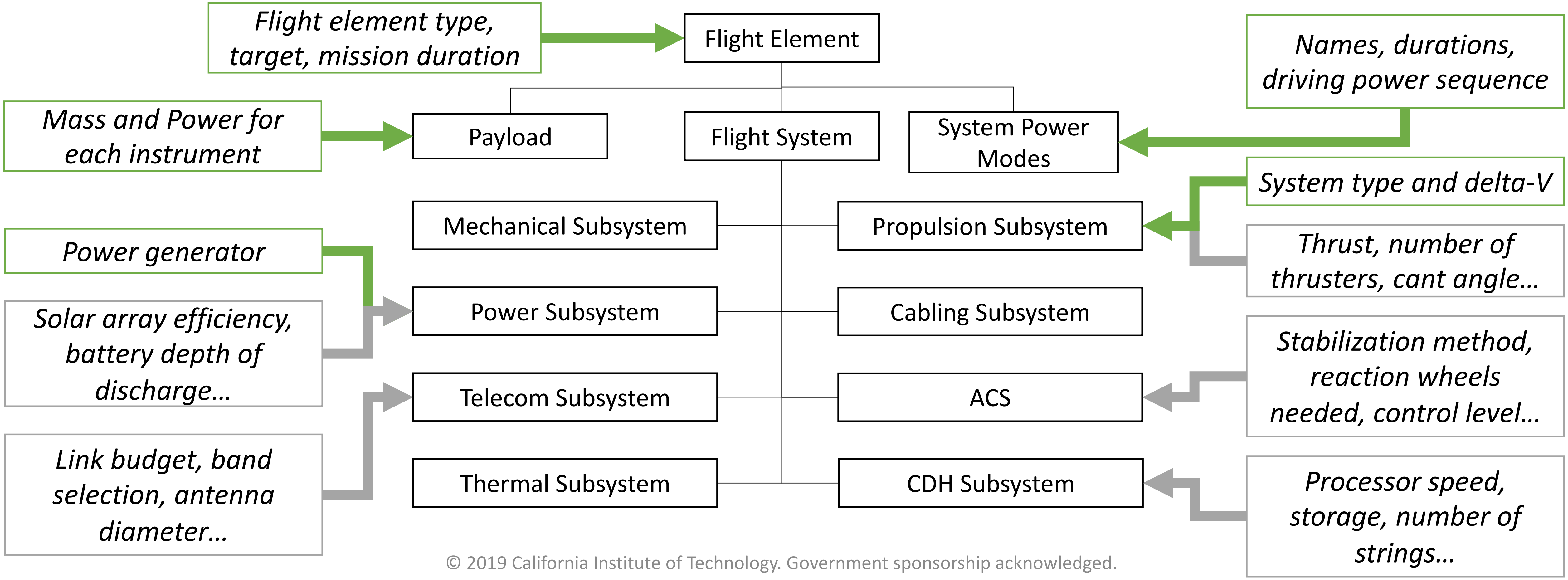
Model tree follows typical spacecraft architecture hierarchy, created by nesting blocks in IME





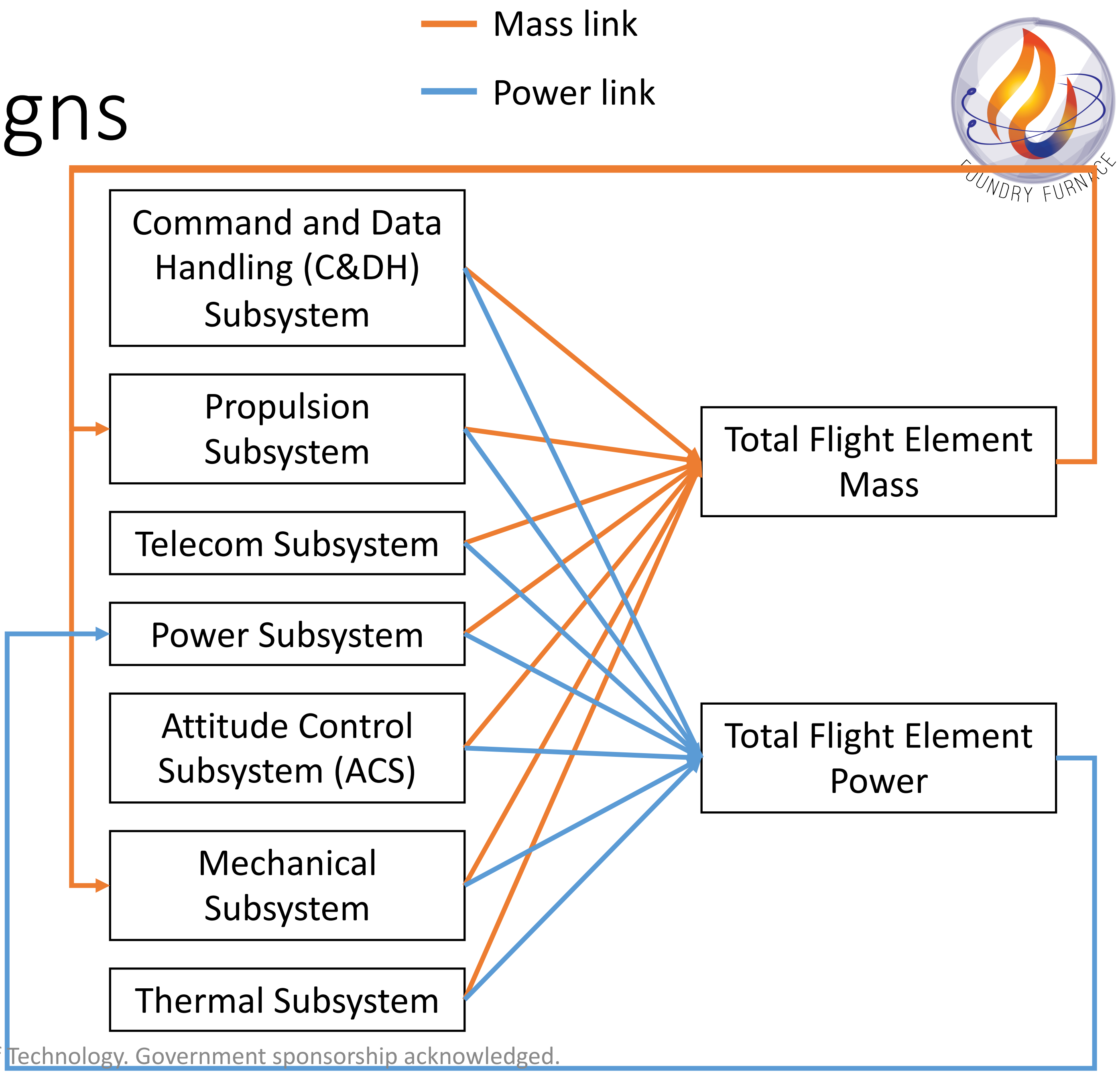
TATER Inputs

User starts with a pre-configured template that includes a default value for every flight system input. Results increase in accuracy and fidelity with better inputs.

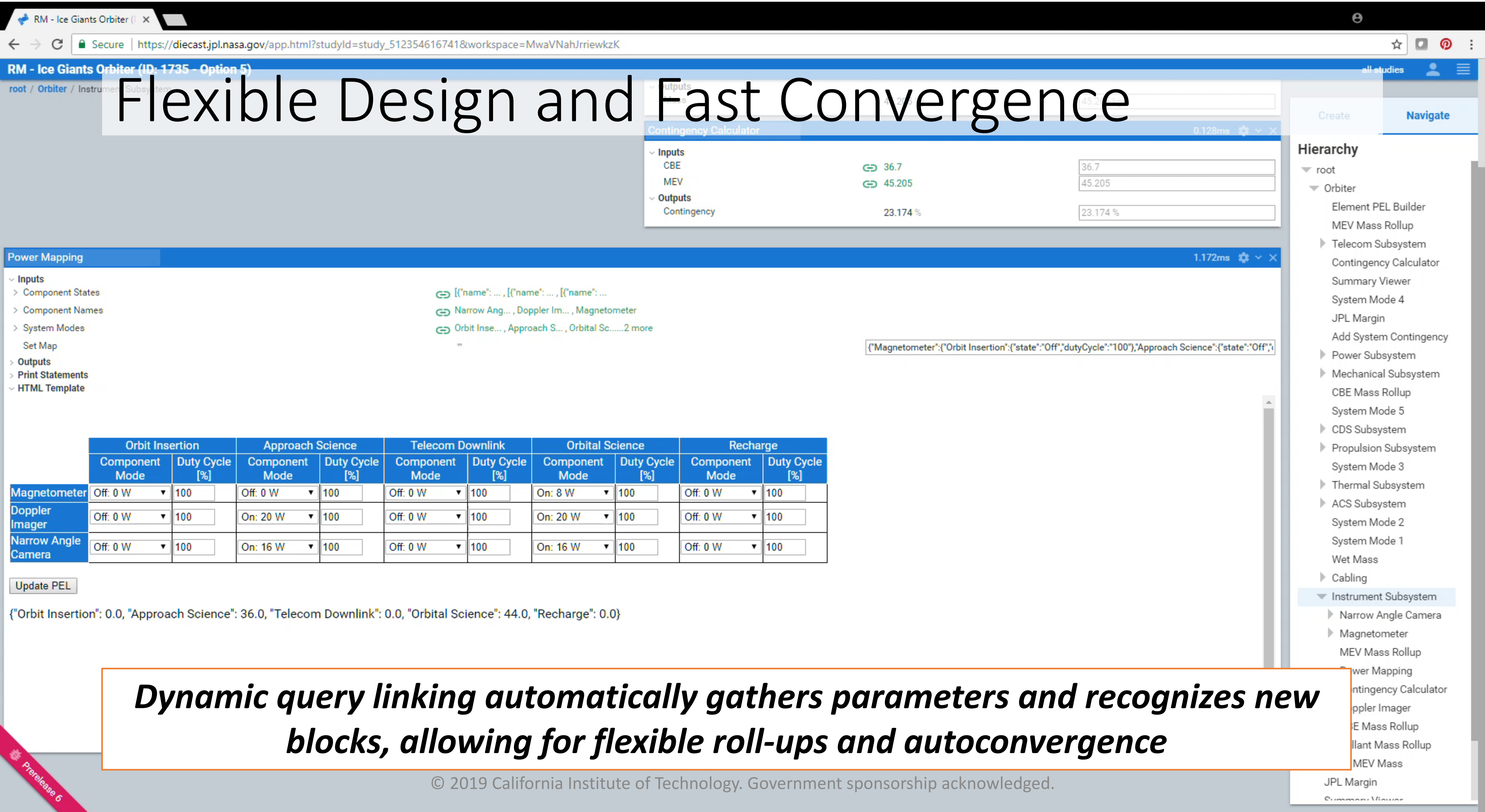


Self-Consistent Designs

Through an intricate web of linked models and data blocks, TATER captures subsystem dependencies and produces self-consistent and converged designs



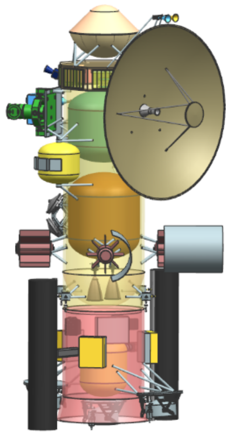
Flexible Design and Fast Convergence



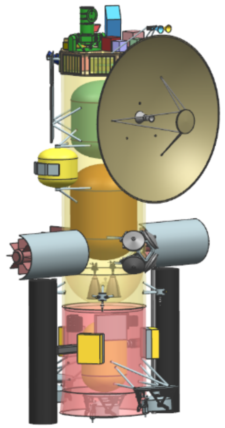
Dynamic query linking automatically gathers parameters and recognizes new blocks, allowing for flexible roll-ups and autoconvergence

Verification and Validation

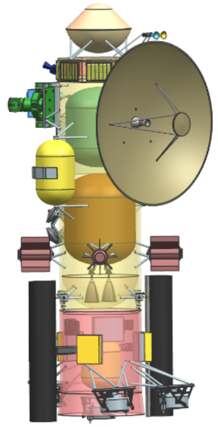
Compared Team X and TATER subsystem masses for the six options studied in the 2017 Ice Giants pre-Decadal report



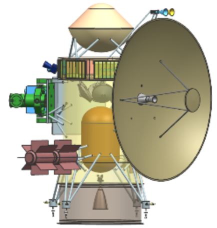
Option 1:
Uranus orbiter
SEP stage
Probe



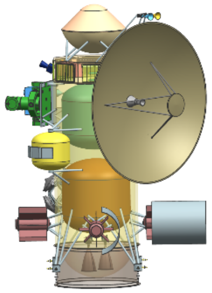
Option 2:
Uranus orbiter
SEP stage
No probe



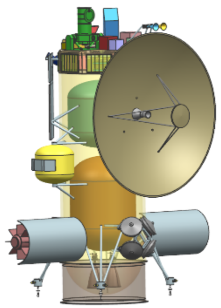
Option 3:
Neptune orbiter
SEP stage
Probe



Option 4:
Uranus fly-by
All chemical
Probe



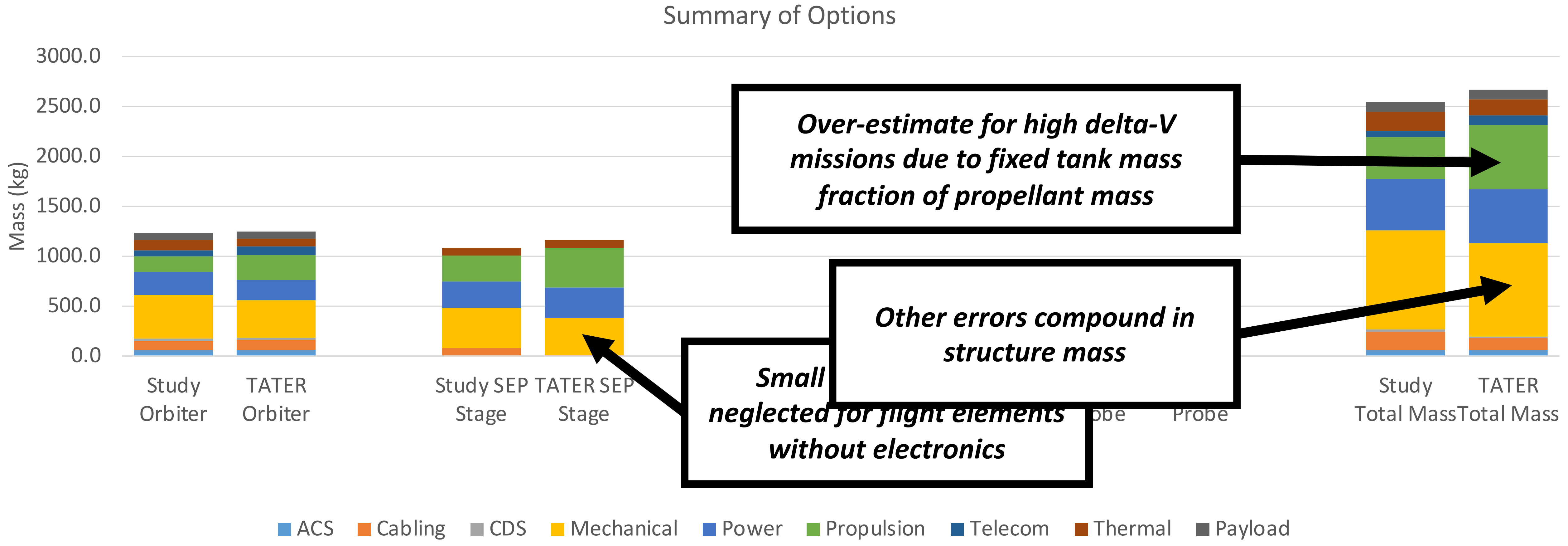
Option 5:
Uranus orbiter
All chemical
Probe



Option 6:
Uranus orbiter
All chemical
No probe

Verification and Validation

TATER matched the Ice Giants study results to within 14% at the flight element level



Conclusions and Future Work

TATER is ready for application to mission studies in A-Team

Model Improvement

- Resolve discrepancies identified in initial validation exercise
- Repeat validation
- Increase validation scope to include power, cost, and wider range of architectures
- Add capabilities and models for selected subsystems and new technologies

Software Improvement

- Explore multiple architecture options and perform Monte Carlo trades
- Time-dependent sequences and states for con-ops

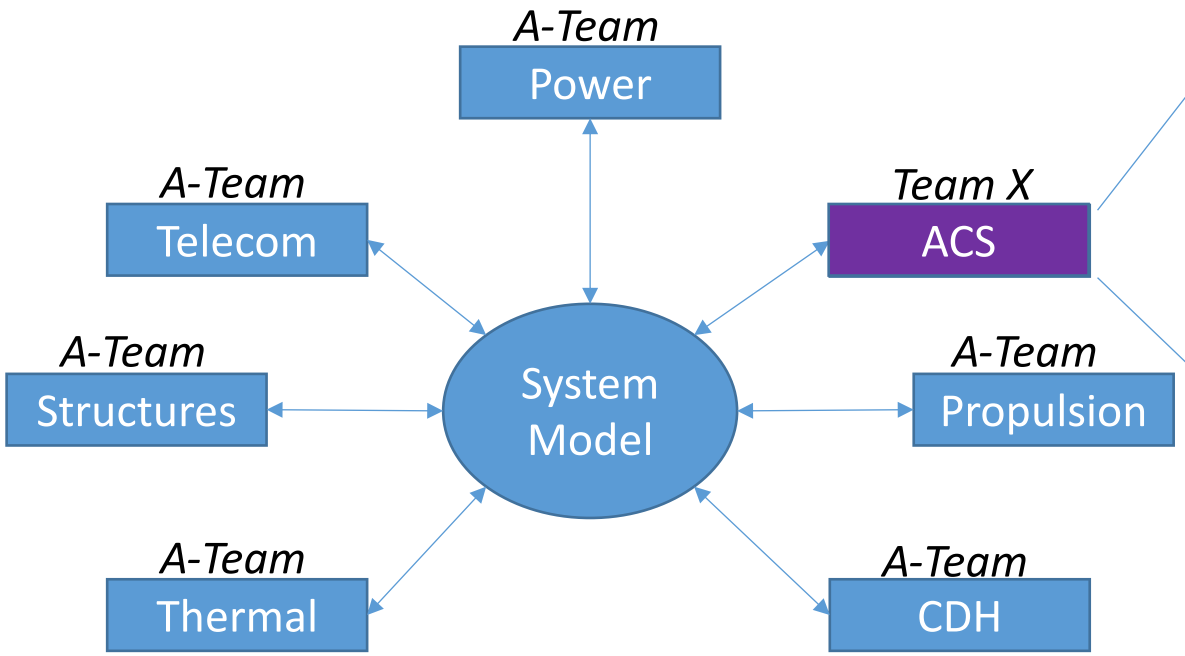
TATER Beyond the A-Team

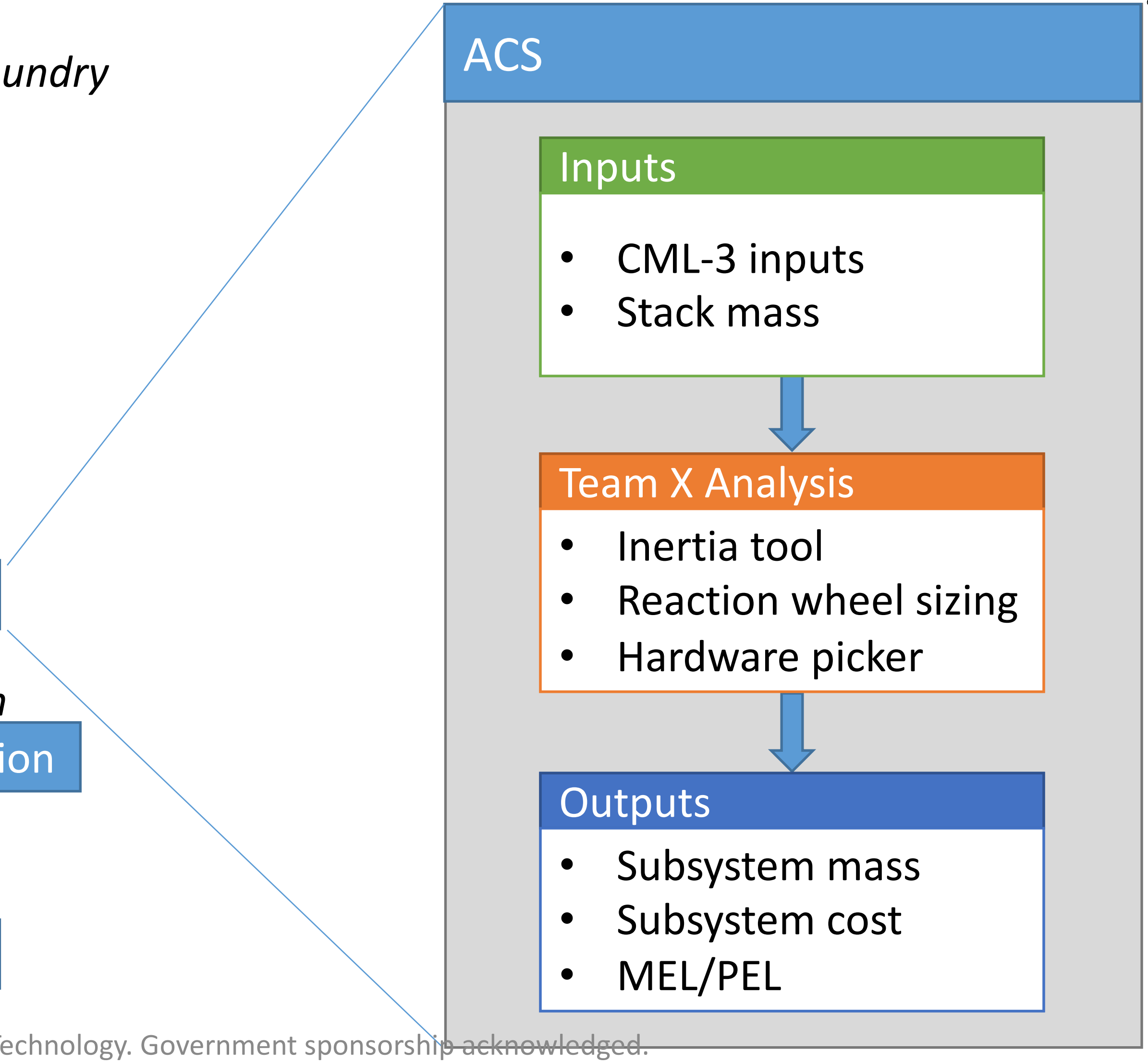
Common system-level architecture across the Foundry

Drag-and-drop replacement of models

Do deep dives and increase fidelity

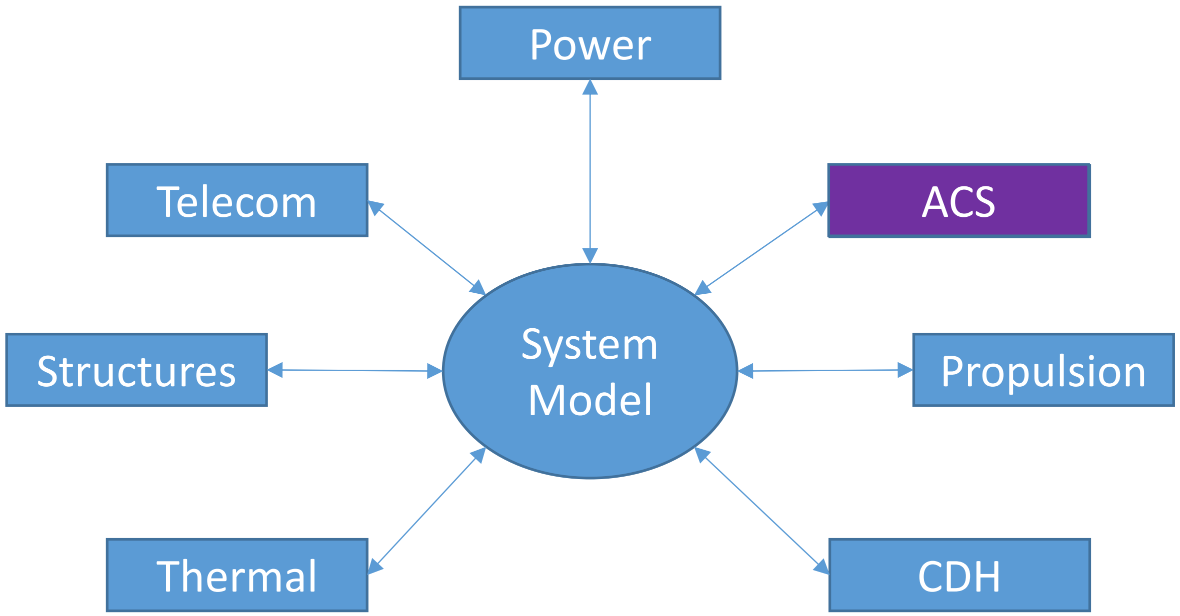
Side-by-side comparison of versions

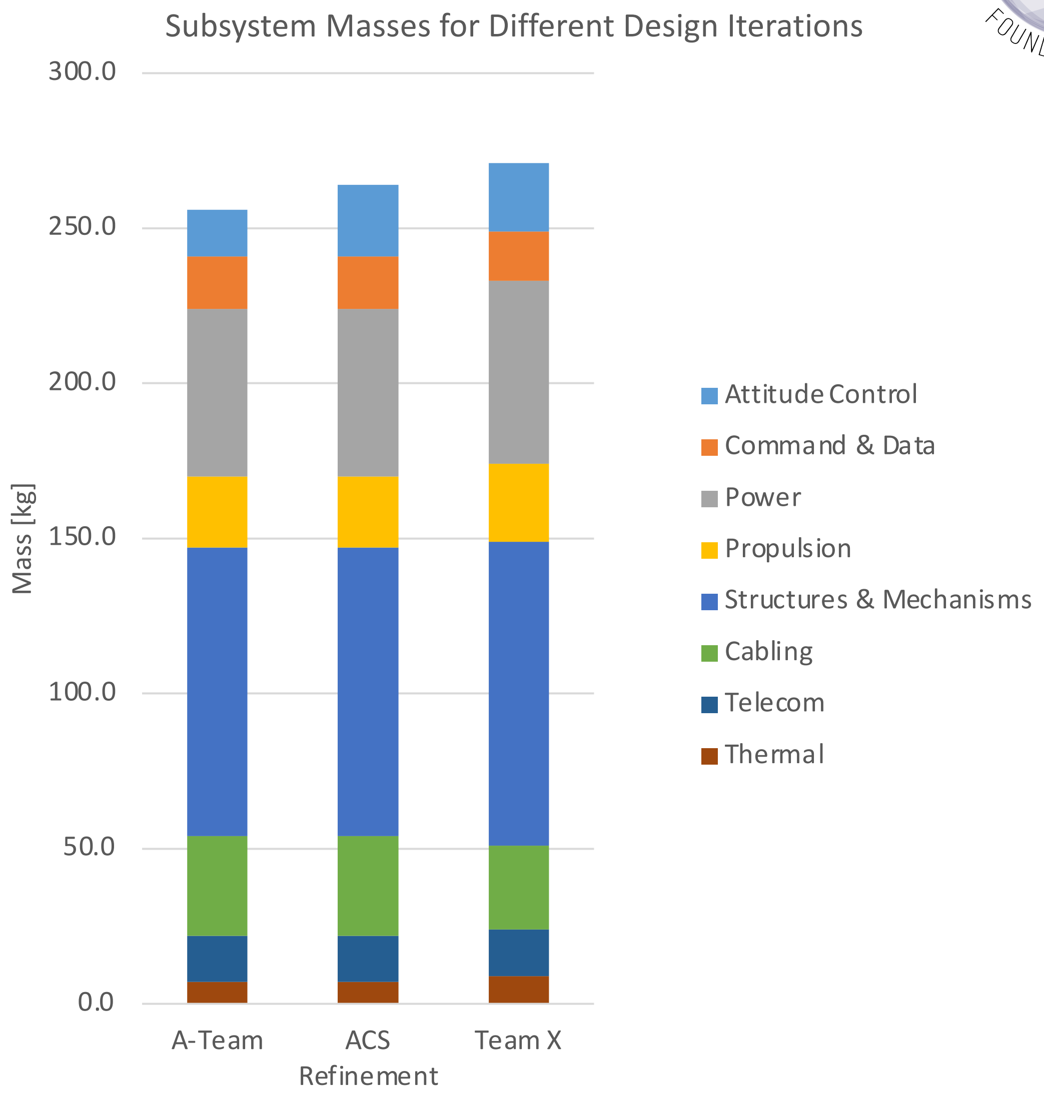




TATER Beyond the A-Team

Common system-level architecture across the Foundry
Drag-and-drop replacement of models
Do deep dives and increase fidelity
Side-by-side comparison of versions





Acknowledgements

- JPL Innovation Foundry
- Foundry Modernization team
- JPL Project Systems and Formulation Section (312)

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.